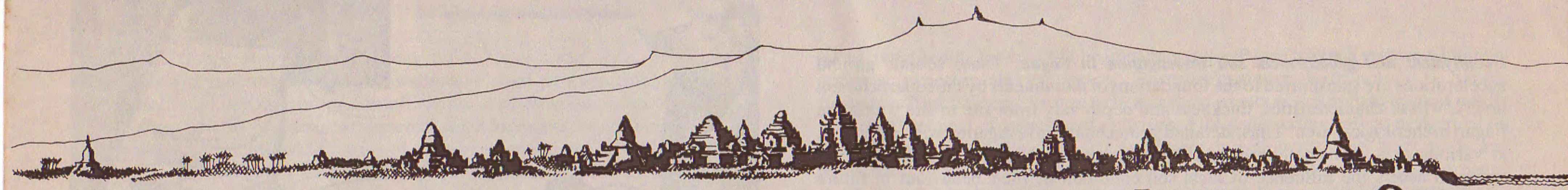


PAGAN newsletter 1983

Strengthening Pagan Monuments

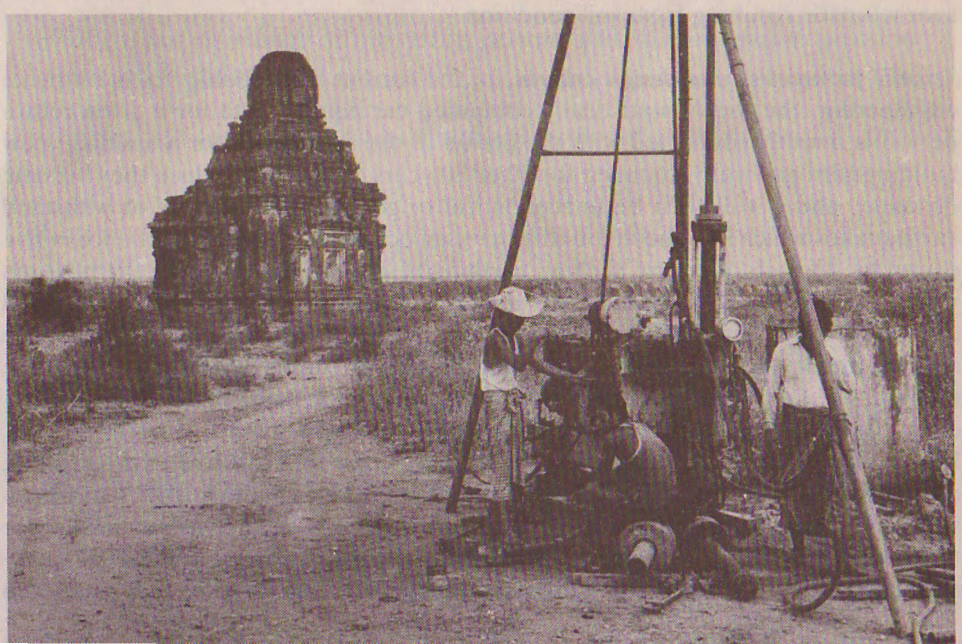
Under the UNDP/UNESCO Project BUR/78/023, the Institute of Earthquake Engineering and Engineering Seismology (IZIIS), from Kiril and Metodij University, Skopje, Yugoslavia, was given a subcontract to develop the methods for improving the ability of Pagan monuments to resist future earthquakes. This task was carried out by a team from Iziis under the leadership of Prof. Predrag Gavrilovic from November 1982 to July 1983, and involved both field work in Pagan and research activities in Skopje.

The field investigations went on in Pagan from 15 November to 15 December 1982. Preparatory steps, carried out by Burmese agencies, included: soil and masonry tests as well as architectural surveys of the selected monuments, partly implemented by photogrammetric methods with equipment and training provided by the project. Soil investigations included: the drilling of seven bore-holes, down to an average depth of 20 metres, at specific locations, the collection and testing of soil samples. Masonry tests were performed by Rangoon Institute of Technology in five monuments, samples being tested under normal and diagonal compression stress. After disregarding atypical values, results fall in the range of 25 to 35 kg/cm² for maximum compression bearing capacity. As might be expected, the compression bearing capacity of the bricks is substantially higher (between 92 and 179 kg/cm²), and the diagonal shear bearing capacity, which involves the tensile resistance of the mortar, is extremely weak, around 0,20 kg/cm². The engineering characteristics of Pagan masonry can thus be seen as result of the use of high quality bricks with very poor mortar. This weakness of mortar is probably more acute now than at the time of construction, as the mud of the original mortar is said to have been mixed with a vegetal resin which has vanished with time, as would be the case with any organical material.

Regional seismological and seismotectonic investigation. After assessment of the geological structure of central Burma and a study of its different morphotectonic units, an evaluation of the seismotectonic activity was carried out. Taking into account the seismic activity of Burma, based on historical and instrumental records, geometrical shapes of potential seismic sources have been defined: firstly, the main linear source is the Sagaing fault, representing a contact zone between the Shan plateau and the Himalaya belt, stretching on a North-South direction for more than 1500 km, and along which earthquakes of magnitude 7 to 8 can be expected, secondly, an area source to the East of the Sagaing fault, where shallow and intermediate earthquakes can be expected with a magnitude up to 7. In addition, it has been found that 80% of the potential seismic activity is located north of the latitude of Pagan (21°N).

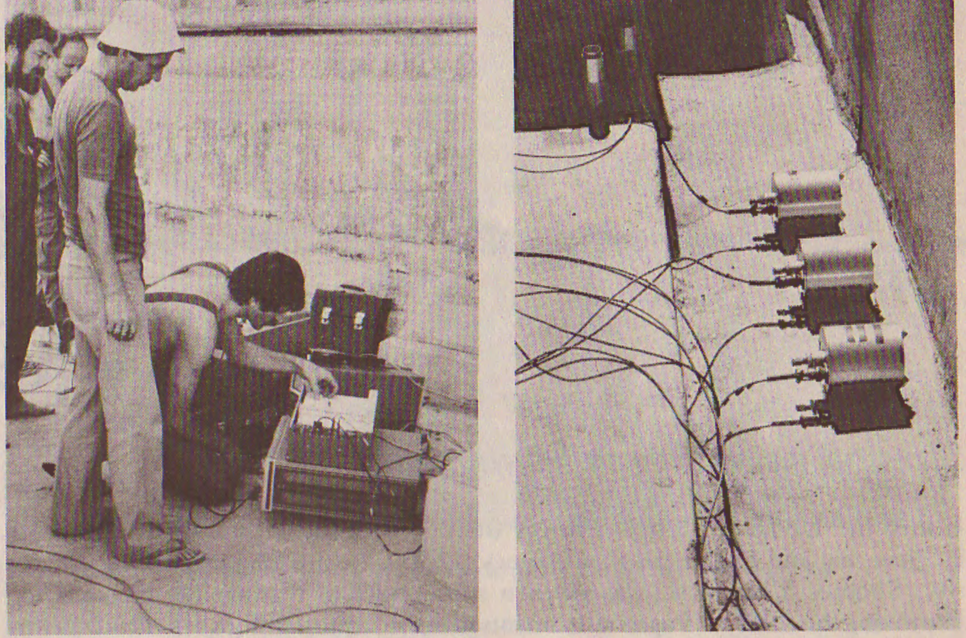
A complex mathematical model of the seismic activity of central Burma was then formulated, incorporating a large number of relevant parametres. From this model, computation of expected maximum ground acceleration was carried out. The results show a high seismicity level, and expected maximum ground acceleration reach, for Pagan, 240 cm/sec/sec for 50 years return period, 300 for 100 years, 460 for 500 years and 530 for 1000 years. The seismicity in the Mandalay region, which lies directly on the Sagaing fault, is even higher with 250,320,480 and 560 cm/sec/sec respectively.

9 August 1982 – Bore-drilling near Yatsauk temple (N° 155) for soil sample collection.



Geophysical and geotechnical soil investigation in Pagan. These seismic ground accelerations are transmitted to the foundations of monuments by the superficial soil layers, whose characteristics, thickness and depth vary from site to site within the Pagan archeological area. Thus, detailed geotechnical investigation was carried out at various sites, principally around the monuments selected for strengthening, in order to assess the influence of local soil condition or their behaviour in future earthquakes.
The Pagan area is an alluvial terrace of the Irrawaddy, consisting of quaternary sand and less frequently gravel, and of clayey sediment deposits. In the first ten metres from the surface, silty and sandy materials, with frequent thin layers of loosely cemented aggregate and weathered silt stone prevail. Geophysical investigations show that the depth of these quaternary sediments varies between 30 and 60 metres.
The investigations included measurement of propagation velocities of longitudinal and transversal seismic waves (refraction seismic profiles), and of ground vibration under microtremors. Using these records, a mathematical model was developed for each site, on which seismic records of different earthquakes were applied to simulate the behaviour of the soil under seismic conditions.
The final results take the form of a single coefficient, the Dynamic Amplification Factor (DAF), specific to each site, which provides a precise evaluation of the expected maximum ground acceleration for each monument. Thus, it has been found that the basic ground acceleration will be increased by the soil characteristics along the Irrawaddy River, from Lokananda stupa (DAF 1,15) to Kyaukku Umin (DAF 1,15), with a maximum increase around Innpaya stupa (DAF 1,40) and Alopyi temple (DAF 1,35) and will be diminished in the Minnanthu area (DAF 0,65). This conclusion correlates with the observed damage of the 1975 earthquake, which affected the monuments around Minnanthu far less than elsewhere: it is important to know that this was not a particular feature of the last earthquake but a permanent characteristic resulting from soil condition.

Seismic parametres and design criteria. In the current methodology of earthquake engineering, the use of statistically computed earthquake data for a given return period is directly connected with the period of use anticipated for a building: new buildings are generally intended for 50 or 80 years of use, after which they become obsolete, and it will then be uneconomical to give them the ability to withstand earthquakes which have been found to have an occurence probability of once in five centuries (though of course such an earthquake could easily strike in the next ten years...). Generally speaking, the anticipated active life of the building will determine the seismic return period to be considered, allowance being made for the specific importance of particular buildings in case of emergency (e.g. hospital, fire stations, etc.) or for the potential induced risk (e.g. great dam, nuclear power plant, etc.), for which it is justified to assure greater protection.
In the case of historic monuments, such criteria are not applicable. On the one hand, a limited life expectancy cannot be easily defined for a building which has been standing for eight or ten centuries; on the other, it is neither economically nor technically possible to provide it with a total resistance against a potential earthquake occuring right on its site. Ultimately, financial availability depends upon each



18 November 1982 – Gawdawpalin temple (N° 1622), station for recording ambient vibrations of the monument, linked by cables with three seismometers.

country's possibilities and priorities and, in a case such as Pagan where a great number of monuments are concentrated in a relatively small area, one must decide between giving the greatest possible protection to one or, at best, few monuments, or giving reasonable protection to a greater number of them.
The selection of design criteria for the strengthening of Pagan monuments is intended to pinpoint the optimum compromise. It has been decided to give them the ability to resist, without damage, a basic seismic acceleration of 300 cm/sec/sec (which corresponds in Pagan to a 100 years return period earthquake), and to sustain, with some damage but without collapse, a basic seismic acceleration of 500 cm/sec/sec (which is expected with a return period of between 500 and 1000 years).

Dynamic proprieties of structures. Experimental testing of structures was carried out by the Iziis team on 15 selected monuments, among them few monuments of exceptional value, the testing of which yielded results directly applicable to the design of their own strengthening, and other monuments, of various sizes and configurations, each of them representing a type whose study provided data which could be used in the repairing of a whole range of comparable structures all around Pagan.
On each monument, full scale ambient vibrations (naturally induced by wind and microtremors) were recorded at significant levels and on two perpendicular profiles. Field equipment for such tests is easy to carry and consists of three seismometers linked by cables with a signal amplifier, a magnetic tape recorder, a Fourier analyzer and a tracing table, which provide, on the site, an initial processing (amplitude and phase spectra).
For all tested structures, the computed dynamic properties include resonant

frequencies, mode shapes and damping ratio. Using these data, mathematical models for dynamic response analysis were established, and a general relationship for calculation of dynamic properties of other structures was developed.
Results show that the first natural frequencies of monuments depend upon the height and excentricity (length-width ratio) of their geometrical elements. Fundamental frequencies range from 2 to 6.5 Hz (i.e. fundamental periods of vibration are between 0.15 and 0.5 second), the highest monuments like Thatbyinnyu or Gawdawpalin having the longest period, around a half second. Mode shapes indicate that the deformation for linear elastic range are of the bending type, and the damping capacity was found to range from 5 to 11%, and will be still higher in case of actual earthquake, a very positive factor which probably explains why the majority of the monuments are still standing after centuries despite the high level of local seismicity.

Strengthening the monuments. The aim of the proposed strengthening is to increase the seismic resistance of the monuments without altering their basic structural system. Structural and dynamic analysis confirms that the present bearing capacity and deformability of the structures do not satisfy the selected criteria for seismic resistance. Moreover, weak points in the structures are localized where abrupt changes occur in their rigidity, resulting in non-linear deformations. This applies mostly in the upper parts of buildings, i.e. terraces and sikharas. On the other hand, the lower massive parts are, in most cases, near the requested resistance, and can attain it after an improvement of the bonding strength of the mortar by partial injection of masonries.
Five monuments have been studied in more detail for strengthening purpose. The behaviour of each structural element has been evaluated, using the criteria and data defined above, and selection of the most suitable methods for strengthening was carried out, the first goal being to conserve the structural integrity of the building under seismic conditions. This will allow the monument to behave as a single body instead of separating into several elements, each with its own dynamic characteristics, as was the case in the last earthquake, when the separation between two elements led to large cracks in the masonry and, in the worst cases, resulted in dislocation and collapse.

Several techniques will be used concurrently for the actual strengthening:

- improvement of the bonding capacity of the mortar by cement injection.
- strengthening of vital masonry elements by confinement into light belts of reinforced concrete or reinforced grouting, to increase the ductibility of these structures.
- assuring structural integrity by either reinforced concrete belts or by steel ties inserted in mortar and combined with local masonry injection, the steel ties being slightly prestressed in order to be immediately active, thus preventing the opening of cracks in the masonry.
- local reinforcement of vulnerable parts.

The strengthening project has been drafted out by Iziis for four monuments and the methodological steps laid out in detail for their future application to other monuments.

The strengthening process will be implemented in Pagan and will involve additional training, expertise and equipment. Burmese engineers were present in Skopje during the final phase of the research, and experiments as well as field training will be an important part of subsequent activities. Full scale testing will be performed on ruined structures in Pagan, such as cement injection of some brick walls and assessment of their physical characteristics before and after treatment, in order to verify the design hypothesis and to select accurately the most efficient material, density and depth of injection. The relevant equipment will have to reach the site in advance.
The complete technical report by Iziis, in six volumes, covers extensively each methodological step and gives a complete presentation of recorded data and dynamic evaluation. The report has been sent to the Burmese agencies involved in the conservation of Pagan monuments and will be further available for consultation at specialized international information centres such as Unesco, Icomos or Iccrom. In addition, copies will be given to a few leading centres of earthquake engineering research around the world, as this exhaustive and scientific approach to the problem of the conservation of historic monuments and ancient masonry buildings will be of considerable interest to specialists in this field.

PAGAN *newsletter*

is published once a year during the Project's duration.

Kindly send us names of interested persons and institutions for inclusion in our mailing list.

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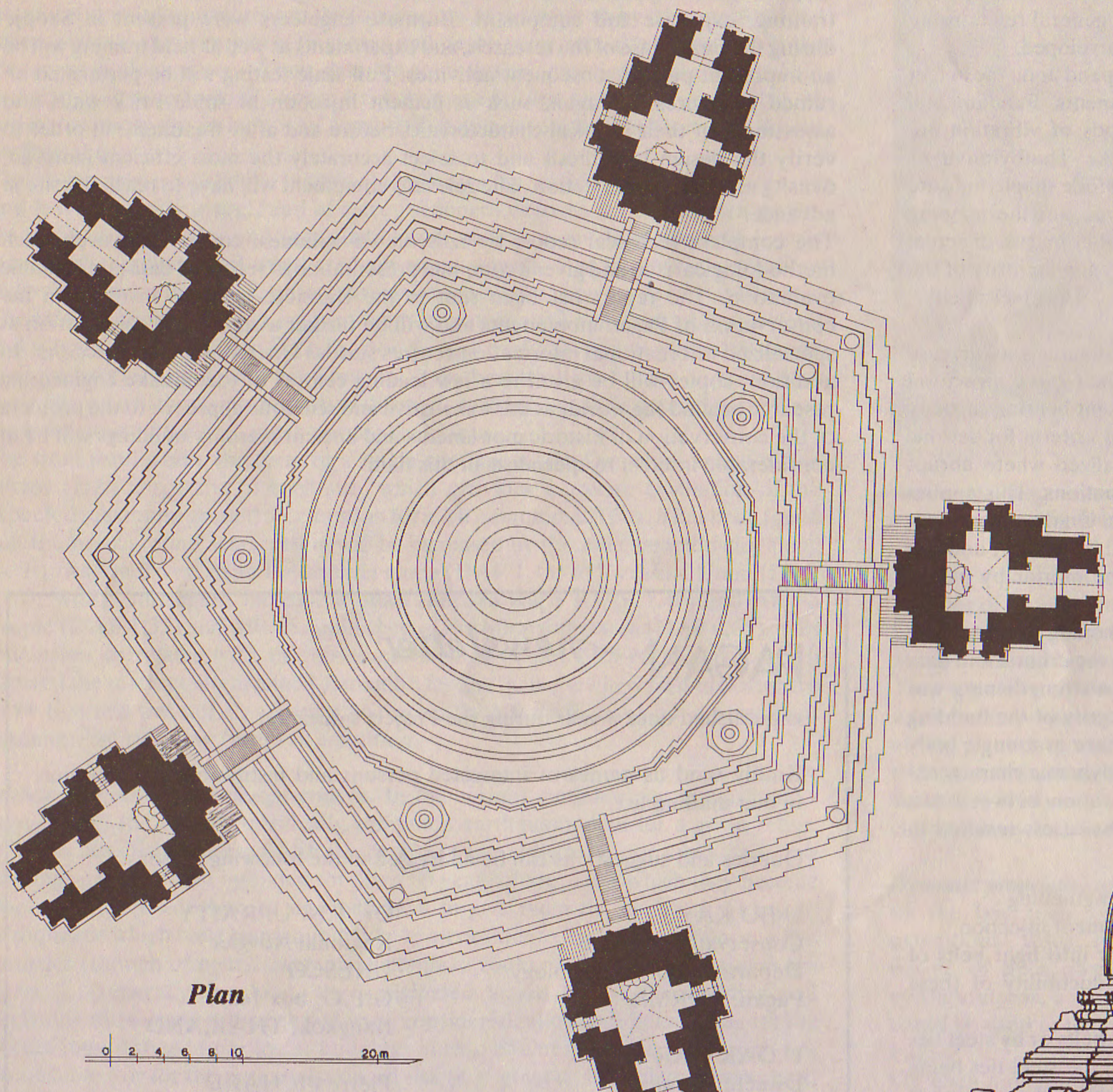
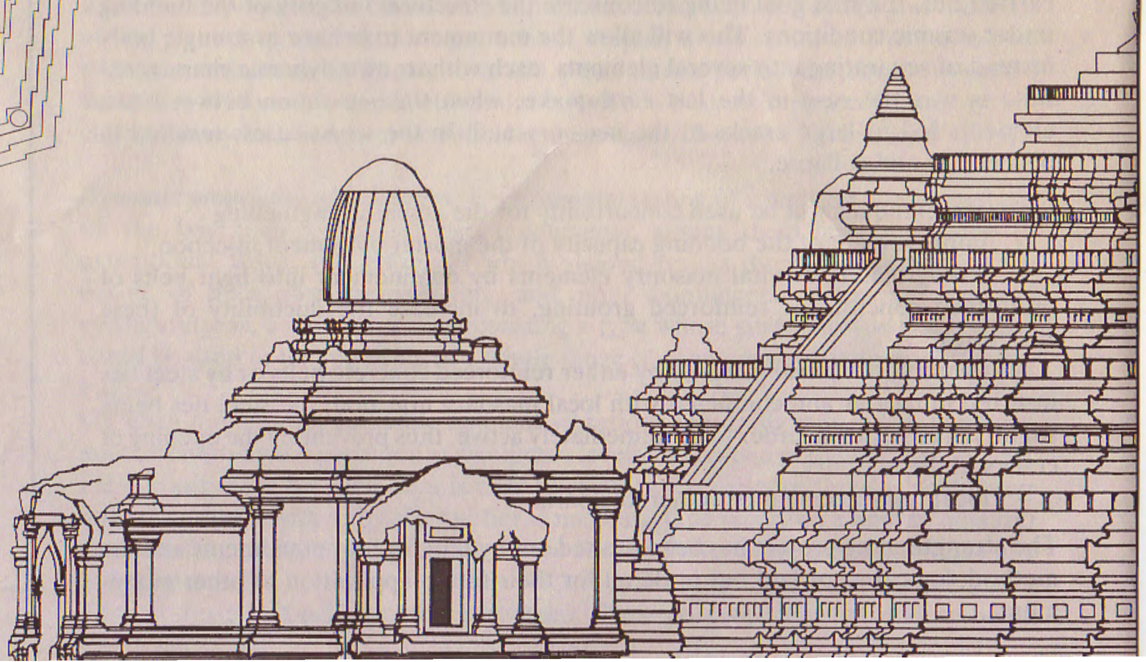
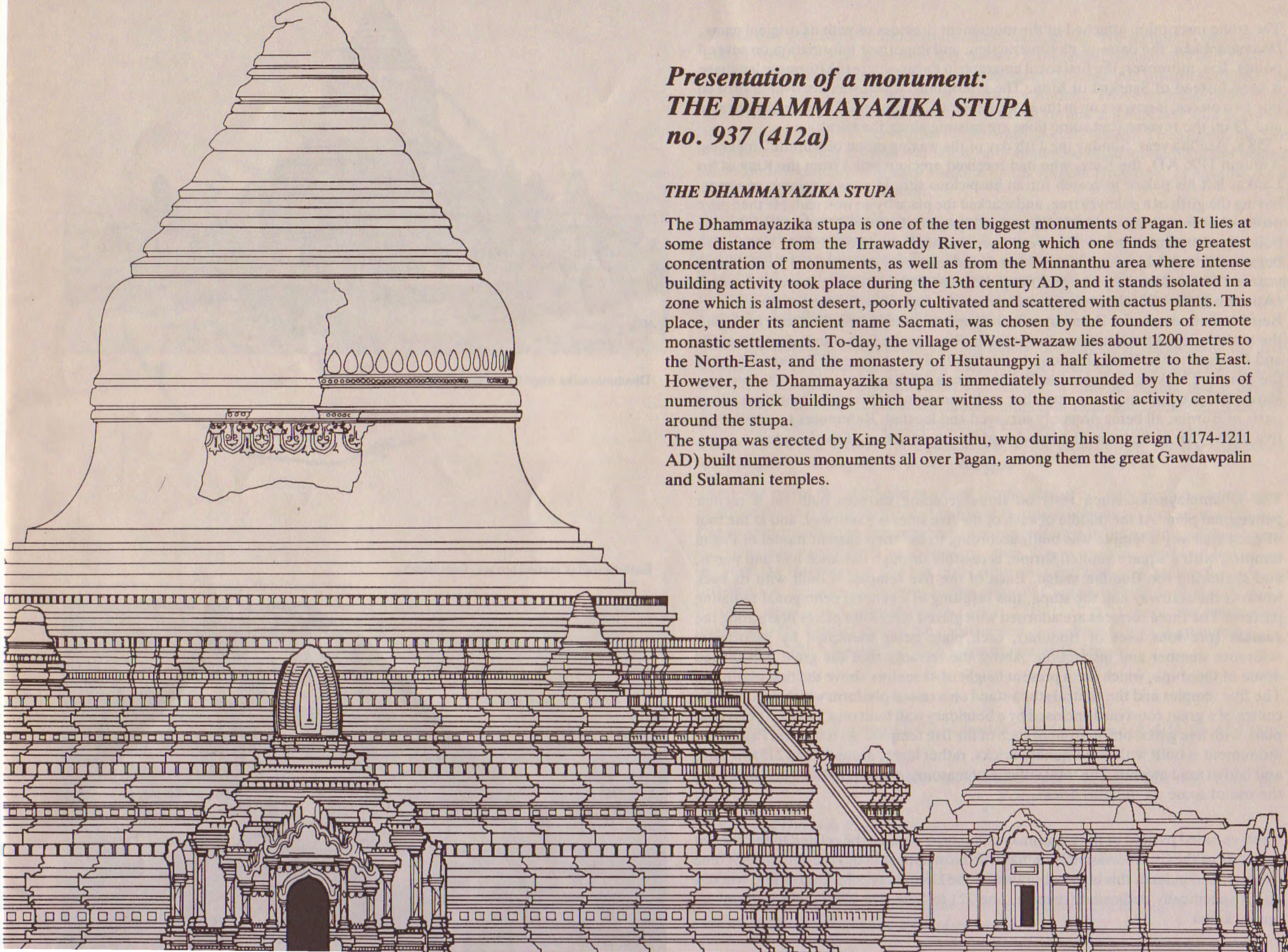


Plan



East elevation (partly from photogrammetric survey by I.G.N. Paris)



Presentation of a monument: THE DHAMMAYAZIKA STUPA no. 937 (412a)

THE DHAMMAYAZIKA STUPA

The Dhammayazika stupa is one of the ten biggest monuments of Pagan. It lies at some distance from the Irrawaddy River, along which one finds the greatest concentration of monuments, as well as from the Minnanthu area where intense building activity took place during the 13th century AD, and it stands isolated in a zone which is almost desert, poorly cultivated and scattered with cactus plants. This place, under its ancient name Sacmati, was chosen by the founders of remote monastic settlements. To-day, the village of West-Pwazaw lies about 1200 metres to the North-East, and the monastery of Hsutaungpyi a half kilometre to the East. However, the Dhammayazika stupa is immediately surrounded by the ruins of numerous brick buildings which bear witness to the monastic activity centered around the stupa.

The stupa was erected by King Narapatisithu, who during his long reign (1174-1211 AD) built numerous monuments all over Pagan, among them the great Gawdawpalin and Sulamani temples.

The stone inscription attached to the monument provides us with its original name, ***Dhammarājaka***, the dates of its construction, and important information on several points. It is, moreover, the first royal epigraph in Pagan where the Burmese language is used instead of Sanskrit or Mon. The inscription, which was discovered broken into two pieces, is now set up in the eastern temple. It contains 35 lines on the obverse and 29 on the reverse (but some lines are missing along the break).

"558 s. Asadha year, Sunday the 13th day of the waxing moon of Santhu", meaning Autumn 1196 AD, the King, who had received precious relics from the King of Sri Lanka, left his palace in search for an auspicious site. He saw a column of vapor, having the girth of a palmyra tree, and marked the place by an iron nail. He then gave orders that an amount of 44,027 ***Klyap*** and 18 ***pay*** of silver should be set aside for the building of the monument. One year later, in the Autumn of 1197 AD, the work began and the bricks were laid on a stone foundation mat. At the end of the following year in "560 s., Bhadra year, on Friday the second of the waxing moon of Santhu" (Autumn 1198 AD), the crown was fitted on the top of the finished stupa.

Besides these dates, the Dammayazika inscription gives, for the first time in Pagan, the boundaries of the kingdom: the Salween River to the East, the Bahuwanna hills and Patikara to the West, Tagaung to the North, Tenasserim and Twavari Nagar to the South. The king dedicated to the new stupa 1000 monks' robes, 500 Burmese slaves and 500 Indian slaves, together with numerous agricultural lands in various parts of Burma, all being precisely surveyed and located. References to administrative units, give us first hand knowledge of the organisation of the kingdom

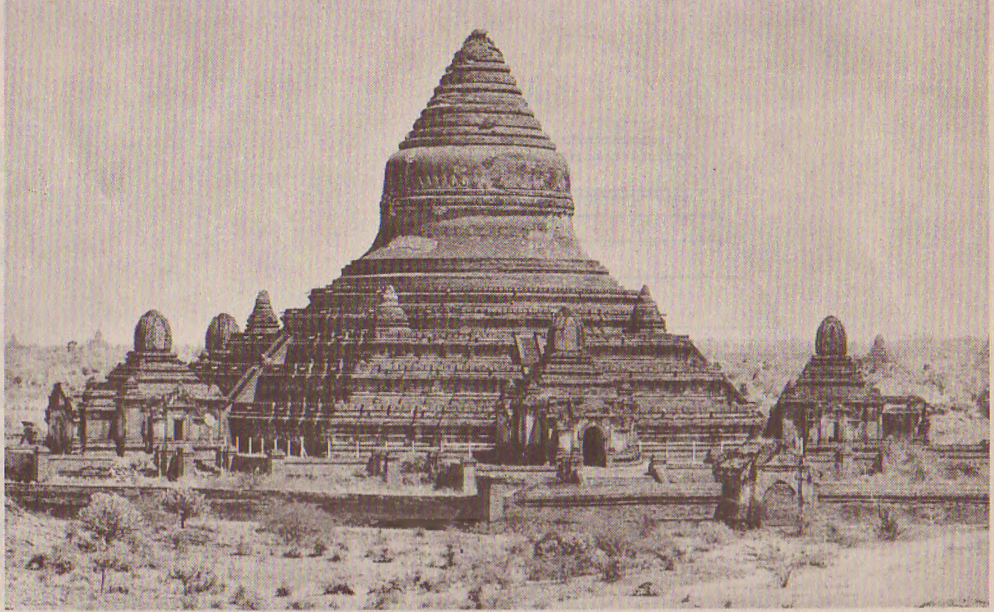
*

The Dhammayazika stupa rests on three receding terraces built on a regular pentagonal plan. At the middle of each of the five sides is a stairway, and at the foot of each stairway a temple was built, according to the then current model of Pagan temples, with a square vaulted shrine, accessible through entrance hall and porch, and sheltering the Buddha image. Each of the five temples is built with its back towards the stairway and the stupa, this resulting in a general pentagonal radiating pattern. The three terraces are adorned with glazed terracotta plates illustrating the ***Jatakas*** (previous lives of Buddha), each plate being identified by its original reference number and inscription. Above the terraces rises the great bell-shaped dome of the stupa, which has a present height of 41 metres above the first platform.

The five temples and the central stupa stand on a raised platform which occupies the centre of a great courtyard enclosed by a boundary wall built on a 15-sided polygonal plan, with five gates, one in front of each of the five temples. As is usual in Pagan, the monument is built with good-quality bricks, rather large, around 420×215×62 mm, and laid in mud mortar. The total volume of masonry is around 44,000 m3, involving the use of some six millions bricks.

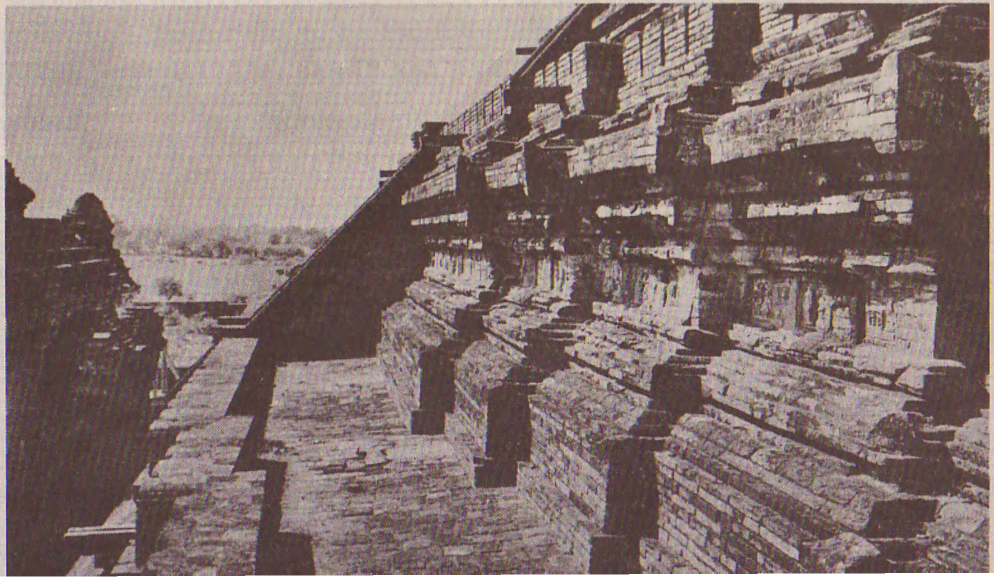
*

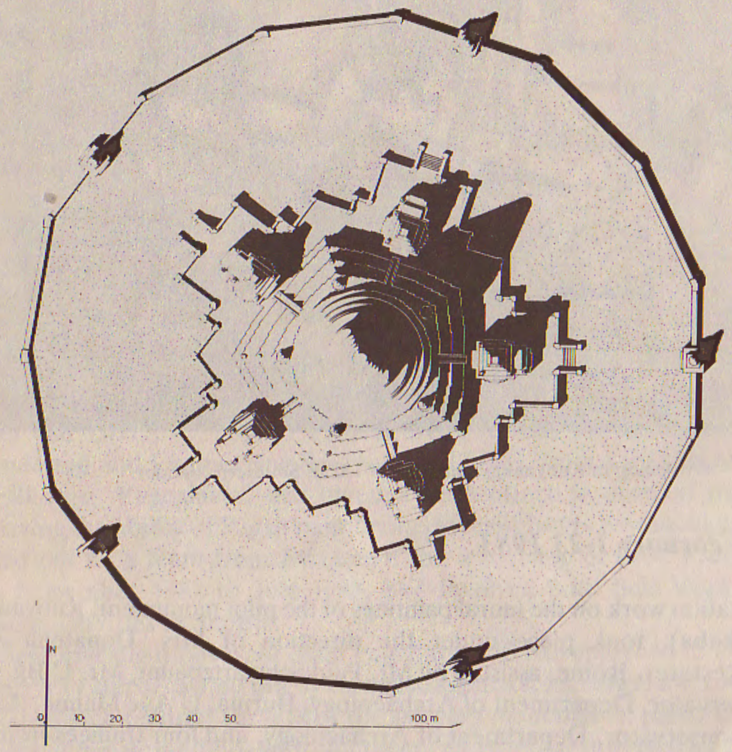
The five-sided pattern of the Dhammayazika stupa is said to be related to the ancient tradition of the five successive Buddhas who must appear in our present cycle of time (***Kalpa***), and indeed, this is corroborated by the Dhammayazika inscription, where a gift is specifically dedicated (reverse, line 22) to "the five Holy Ones born in this happy kalpa".



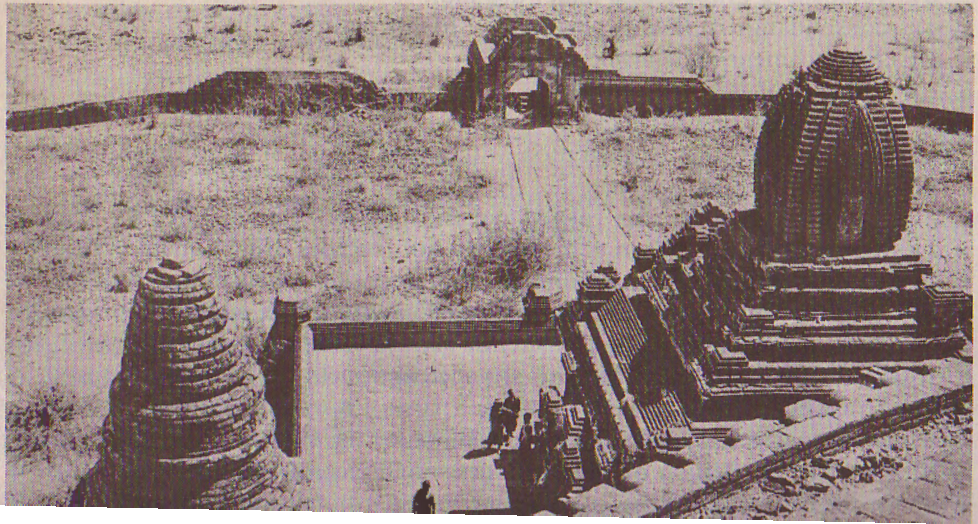
Dhammayazika stupa from South-West.

Eastern wall of second terrace, from North.





Eastern temple and gateway, from North-West.



Moreover, according to modern tradition, each of the five temples is dedicated to one of these five successive Buddhas, namely Kakusanda, Kongamana and Kassapa, who attained enlightenment in the remote past, Gotama, the historical Buddha of the 6th century BC, and Metteyya, the future Buddha. However these dedications are not confirmed by any contemporary inscription and can only be found in graffiti from the 16th and 17th centuries on the walls of each temple. Then again, the five images are, in their present condition, very similar, and the mural paintings behind them do not differentiate each Buddha by his specific Holy tree, as must be done according to Buddhist tradition.

Though the Dhammayazika stupa is by far the greatest and best known of the pentagonal monuments in Pagan, it is not the unique example: a total of 17 monuments have been identified, 16 in Pagan and one in Salé (a city 50 km south of Pagan). Most of them are temples, not stupa, with a central pentagonal core, a circumambulatory corridor, five entrances and five images of Buddha, hence their name ***Ngamyethna***, (meaning five entrances).

These pentagonal monuments are absolutely original. The tradition of the five Buddhas of our time comes from the early centuries of Indian Buddhism, and, though it pervaded other Buddhist countries, it is only in Burma that it can be connected with pentagonal monuments. Temples in India and indianized countries like Cambodia, Sri Lanka, Indonesia, etc., are nearly always built on a perpendicular frame plan, using a square or a quadrangle, as the basic design. The few exceptions are octagon or hexagon, but never pentagon.

Then, the use of the pentagon as a base for the plan of not only one but a whole serie of monuments is the distinctive creation of Burmese architects. The ngamyethnas of Pagan are probably the first regular five-sided buildings in the world, and their shape has remained exceptional up to modern times. It was experimented with in Europe between the Renaissance and the 18th century in a few instances, mainly for military fortification. Besides the famous Italian castle of Caprarola (built in 1559 AD) and a baroque church in Czechoslovakia (Zdar, 1719-1722 AD), very few pentagonal buildings were erected before the construction of the Pentagon in Washington D.C. (1941-1943) which houses the U.S. Department of Defence.

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Conservation of Mural Paintings and Stuccoes

As part of the UNDP Project BUR/78/023 two missions for the conservation of the stuccoes and mural paintings of Pagan have been undertaken by ICCROM, the International Centre for Conservation, Rome, under Unesco contract and at the request of and in Collaboration with the Department of Archaeology, the Socialist Republic of the Union of Burma. The following briefly describes the objectives of the missions and the work carried out in 1982 and 1983.

Mission I, February 14 _ 23 1982

This mission was carried out by Mr. Paul Schwartzbaum, Chief Conservator/Restorer, ICCROM, and Mr. Ottorino Nonfarmale, Conservator/Restorer, Bologna, Italy, in collaboration with U Ba Tint, Archaeological Chemist, Department of Archaeology, Burma, and Mr. Pierre Pichard, International Coordinator, Pagan Project UNDP. Sixteen monuments were inspected. The objectives of the mission were to:

– familiarise the visiting conservator/restorers with the physical characteristics of the mural paintings and stuccoes and the problems of conservation to which they are subject;
– evaluate conservation treatments to date on the stuccoes and mural paintings of Pagan;
– evalutate the efficacity of possible conservation treatments;
– collect samples for the analyses of the component materials and techniques of execution of the stuccoes and mural paintings; and
– based on data provided from the above, make recommendations for a program of conservation at Pagan and the continued training of Burmese personnel in the most up-to-date conservation techniques.

Proposed Conservation Treatments: Test conservation treatments were carried out by Mr. Schwartzbaum and Mr. Nonfarmale with the methods developed on ICCROM projects in other parts of the world, whose efficiency has been confirmed through years of application in the field. A number of cleaning tests were made for the removal of surface accumulations, old oil fixatives, bat excrement and whitewash from the mural paintings. At Kubyaukgyi Temple (Myinkaba) it was possible to remove the surface accretions in the areas tested to the point that the original pastel colours of the paintings were exposed in all their subtlety.
Methods for the consolidation of friable stuccoes were also tested. Deteriorated areas were impregnated with a solution composed of lime water with a small addition of acrylic resin emulsion (Primal AC 33), applied through compresses of paper pulp.

Collection of Samples for Analysis: Samples were taken to identify the original pigments and determine the stratigraphy of the mural paintings. The analyses were carried out by Dr. Lorenzo Lazzarini, geologist, Scientific Laboratory of the Superintendent of Artistic and Historic Property, Venice.

17 February 1983 – Workshop in Kubyaukgyi temple (N° 1323). Southern corridor.

Mission II: February 1-23 1983

Actual conservation work on the mural paintings of the pilot monument, Kubyaukgyi Temple (Minkaba), took place under the direction of Mrs. Donatella Zari, Conservator/Restorer, Rome, assisted by Mr. Paul Schwartzbaum, Mr. U Ba Tint, Chemist/Conservator, Department of Archaeology, Burma, U Aye Maung, Assistant Chemist/Conservator, Department of Archaeology, and four trainees from the Pagan area.
In the course of the work, the mural paintings were studied and their state of preservation and agents of deterioration documented. Several tests of conservation treatments were enacted:

a) removal of a film of polyvinyl acetate previously applied to the painted surface;
b) removal of grime found under this film;
c) consolidation of flaking paint and of friable plaster;
d) reattachment of detached plaster;
e) removal of cement fillings;
f) execution of new fills; and
g) discreet pictorial reintegration with water color glazes in areas of small abrasions of the paint surface.

Test treatments were also carried out in Ananda Temple, Lin Pya Temple, Leymetna Temple, and on detached exterior stuccoes using a method recently developed at ICCROM based on the use of a special low alkali hydraulic lime in conjunction with a system of nylon attachments. Other monuments were inspected and recommendations made for various conservation problems, i.e. the treatment of mural paintings and stuccoes in structures seriously damaged by earthquakes.

Proposals were made for further collaboration in 1984 between the Socialist Republic of the Union of Burma, Unesco and Iccrom and arrangements were made for Burmese conservators to continue their training at institutions abroad.